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Computer Simulation for Space Surveillance Network Evaluation

TRAJECTORY ANALYSIS PROGRAMMING DEPARTMENT
Information Processing Division
Engineering Science Operations
The Aerospace Corporation
El Segundo, Calif. 90245

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15 June 1977

Final Report

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AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Dennis Eagan

Dennis Eagan, Captain, USAF
Project Officer

Sandra J. Perry

SANDRA J. PERRY, Lt Col, USAF
Chief, Evaluation & Analysis Div
Dir of Adv Sp Def Capabilities

FOR THE COMMANDER

James E. McCormick

JAMES E. McCORMICK
Colonel, USAF
Deputy for Space Defense Systems

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The design of computer software for large scale scientific simulations often includes the use of existing programs. The software system described in this report was designed to perform Monte Carlo orbit estimation analysis for a study of large scale, highly complex, sensor networks. A requirement imposed was that two existing computer programs were to be used as integral parts of the simulation. This led to the creation of a software system → OVER

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containing several independent software elements, each devoted to a specific function, rather than a single composite program. A separate executive computer program was designed to perform system execution control and to configure input for each system element. Remote console execution of the software system was implemented to facilitate throughput for the large number of computer runs required for analysis purposes.

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PREFACE

This paper summarizes software development accomplished at The Aerospace Corporation, El Segundo, California, under the direction of the USAF Space and Missile Systems Organization. A large number of Aerospace and Air Force personnel were involved in the project. The author would especially like to acknowledge A. L. Blackford, Captain G. G. Carson, W. D. Downs III, R. B. Gladson, J. E. Grant, R. P. Gross, P. T. Guttman, Dr. H. Holtz, Dr. J. L. LeMay, N. W. Rhodus, and L. Whittaker, all of whom either directed or made major contributions to software development.

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FIGURES

INTRODUCTION

The software system described by this paper was developed for the USAF Space and Missile Systems Organization (SAMSO). Development was accomplished at The Aerospace Corporation by a network evaluation (SSNE&O)* project team headed by Dr. J. L. LeMay. The goal of one major project task was the development of the analysis tools (software) for sensor network performance determination. This performance is measured by network generation of sufficient and timely tracking data for operational orbit estimation. The software was to accommodate a large number of runs — well over 1000 combinations of sensor networks with nominal orbits ("scenarios") were identified. Over 40 separate ground- and space-based sensors were scheduled for incorporation in various combinations in a sizable number of candidate sensor networks. Similarly, the "scenarios" of interest encompassed all classes of orbiting objects.

NETWORK ANALYSIS METHODOLOGY

A Monte Carlo analysis tool to ascertain the performance of sensor networks with the current operational orbit estimation procedures was formulated. The basic analysis methodology (Ref. 1) begins with the generation of a reference ephemeris of an object of interest based on highly complex and accurate dynamic models. This reference ephemeris is assumed to provide the "truth" for error estimation purposes. Observations are generated based on the reference ephemeris by sensor models simulating components of the candidate network. These "perfect" observations are corrupted and edited by applying noise realizations obtained by using statistical models of individual sensor performance and outage characteristics. A weighted least squares batch estimate of the object orbit based on the corrupted observations is then obtained. Orbit estimation is performed using software that simulates methods and dynamic models incorporated in operational software. The operational dynamic models differ from the reference model and are generally less complex. Comparison of the estimated object ephemeris and the refer-

*Space Surveillance Network Evaluation and Optimization.

ence or "truth" ephemeris yields a single error-trajectory realization. The entire process (at times excepting the generation of "perfect" observations) is repeated with different realizations of observation noise and other random system parameters until satisfactory statistical confidence can be achieved. A measure of network effectiveness is obtained by repeating the complete set of replications for each object of interest. In general, the requirement to generate results parametrically (an example parameter is tracking duration) leads to performing the entire Monte Carlo process many times.* Finally, overall network effectiveness is assessed by comparing results determined in a like manner for the other candidate sensor networks. A resume of the basic steps for a single Monte Carlo repetition is as follows:

1. Generate "reference" ephemerides.
2. Generate "perfect" observations.
3. Corrupt and edit "perfect" observations.
4. Perform "operational" orbit estimation.
5. Determine error from "truth."

Parameters whose effect on the estimation process may be studied are:

1. Initial object state uncertainty
2. Dynamic model errors
3. Observation noise and bias
4. Sensor location or orbit errors
5. Sensor outage and probability of detection
6. Solar and lunar geometry effects
7. Data transmission delay
8. Sensor tasking for selective object tracking
9. Track time duration

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*This can easily imply a prohibitive number of computer runs. In actuality, covariance analyses are used to supplement Monte Carlo results.

The overall analysis flow is shown graphically in Figure 1.

One of the most important and time-consuming facets of the SSNE&O project was the collection of information describing sensor and object characteristics. Data for each of the following categories were necessary for numerous existing and proposed sensor systems.

1. Location or orbit (space-based sensors)

2. Survey errors or orbit uncertainties

3. Visibility constraints

4. Observation type

5. Data rate or scan times

6. Observation noise and bias statistics

7. Downtime probability

8. Pipeline delay time

The following information was necessary for the large number of scenarios of interest.

1. Initial epoch time and state conditions

2. Ballistic coefficient

3. Time and magnitude of orbit adjusts

4. Size and spectral characteristics

5. Duration of flight

SOFTWARE SYSTEM DESIGN

The analysis software used for the Space Surveillance Network Evaluation and Optimization (SSNE&O) project is required to model accurately existing and proposed sensor types and to simulate the operational orbit estimation process used by the Aerospace Defense Command (ADCOM). Two

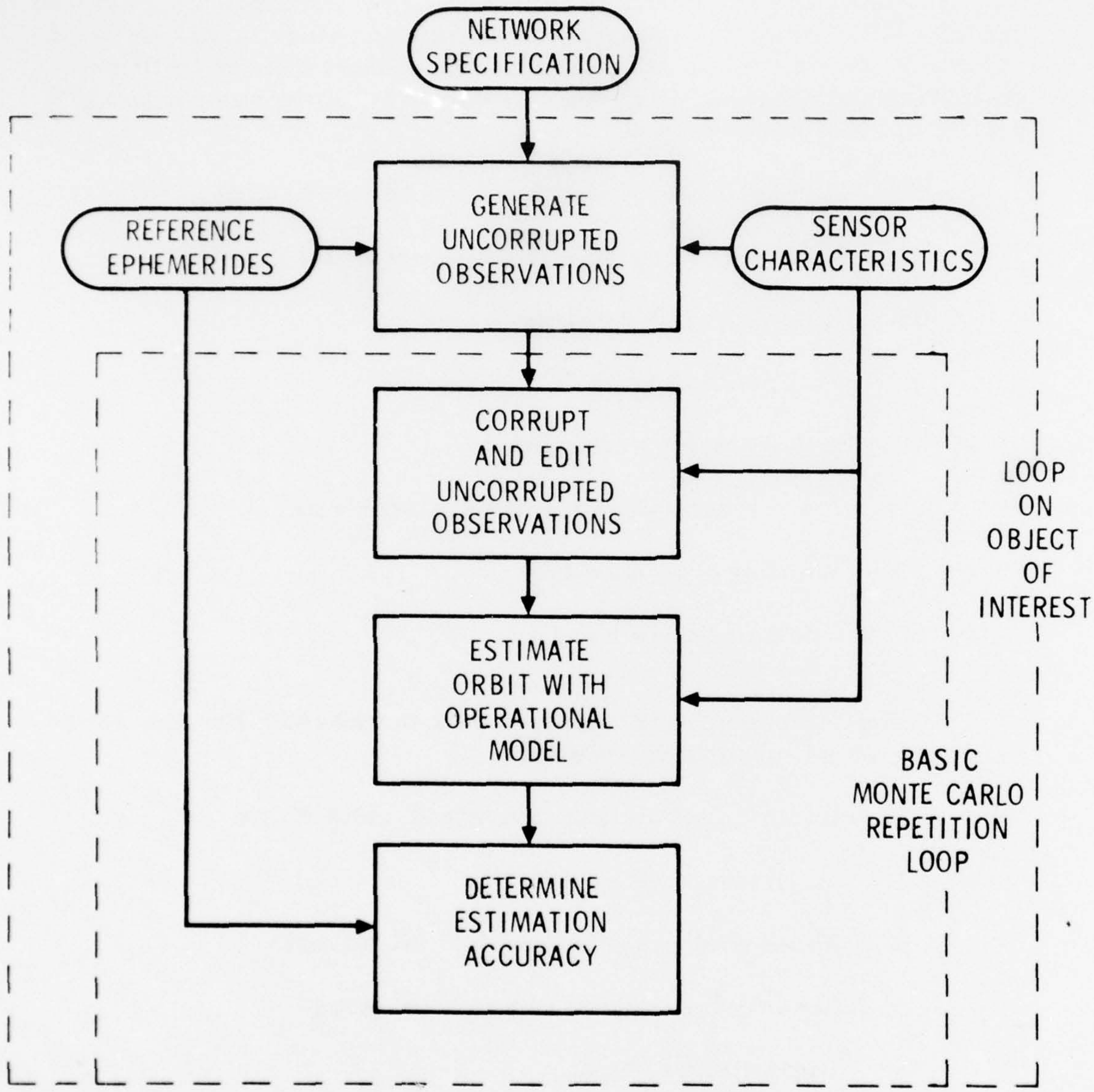

Figure 1. Network Analysis Methodology

existing pieces of software were specified to accomplish the above functions. These two programs, namely, DETECT and TRACE, have been thoroughly validated and extensively employed in the past. It was felt that their incorporation would speed software development and enhance confidence in analysis results. The specified ground-based sensor observation generator (DETECT) fulfilled the basic sensor modeling requirement that a compromise between standard "geometry" only models and specialized "hardware" oriented models be found. Previous large scale network analysis studies have tended to be "coverage" studies based on sensor models with relatively simplified geometric visibility volumes defined by range, azimuth, and elevation limits. This approach was too simplified for the SSNE&O project. More complex sensor modeling tended toward extremely detailed handling of individual sensor concepts. Detailed sensor modeling was too cumbersome and computationally slow to simulate a large set of separate sensors. The DETECT program models ground-based sensors in what can be called an expanded geometric mode. The basic visibility volume for each sensor is modeled as one or more pointable right elliptical cones as shown in Figure 2. Additional constraints are functions of sun/moon position, object size, and relative motion.

A new space-based sensor model was added to DETECT for the SSNE&O study. This model was designed to be flexible enough to represent all likely space-based sensor concepts. The basic visibility volume is a so-called "coolie hat" about the sensor satellite spin vector. This spin vector may be continuously aligned along the sensor satellite radius or may be inertially stabilized. The "coolie hat" may be maintained at a constant angle with respect to the horizon. The model is provided with a complex scan time specification. Ground and/or space readout constraints may also be specified. The most important aspects of the model, however, are expressions for the computation of signal-to-noise (S/N) ratio for both LWIR (Long Wave Infrared) and visible light sensors. These expressions are relatively complex functions of orbit geometry, object spectral characteristics, and background radiation. Object tracking is possible when all geometric constraints are satisfied and an S/N value above a specified threshold occurs for n of m consecutive times of observation opportunity. Figure 3 represents the basic space-based sensor visibility volume.

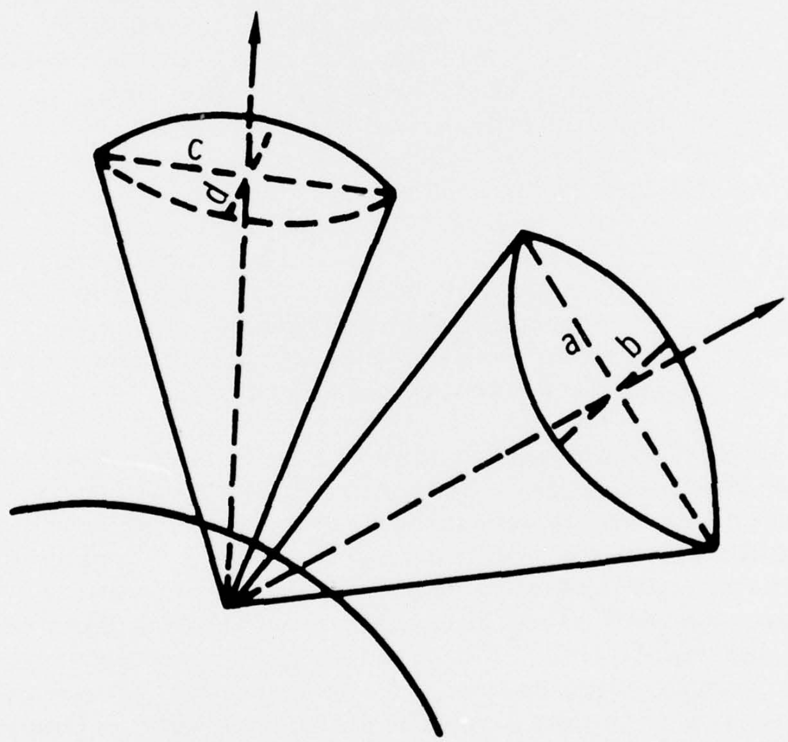

Figure 2. Ground-Based Sensor Visibility Volume (One or More Pointable Right Elliptical Cones)

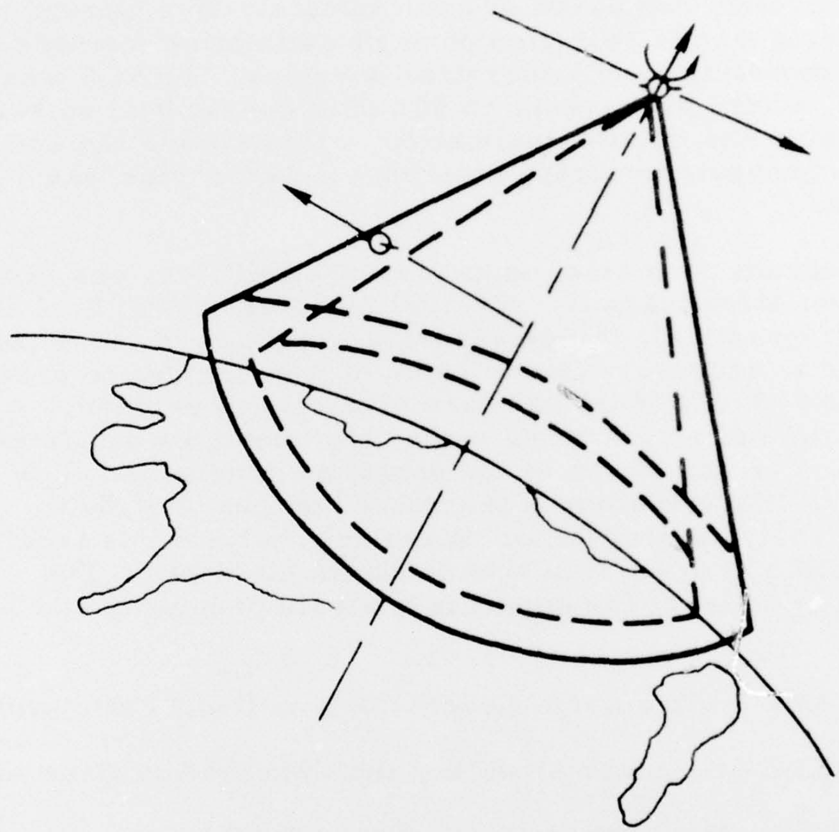

Figure 3. Space-Based Sensor Visibility Volume (Coolie Hat with Complex Scan Model and Spin Axis Stabilization)

The specified ephemeris generation and orbit estimation software (TRACE) has demonstrated the accuracy and flexibility required to generate reference ephemerides and to simulate operational estimation techniques. The TRACE computer program has been used for many years to perform highly complex and accurate orbit estimation studies with both real and simulated observational data. TRACE is a large scale software system composed of approximately 40 separate overlays offering a wide selection of orbit estimation methods, dynamic modeling, and integration schemes. TRACE was modified, where necessary, to simulate operational software. An extensive and detailed validation of this simulation and the ability to generate accurate reference ephemerides was performed.

Program core size, input incompatibilities, and project completion dates made the physical merging of DETECT and TRACE impractical. Since separate execution of these two programs is necessary in any case, it was decided to create a structure of individual software elements to perform specific simulation functions rather than design a single piece of software or add to one of the specified programs. The SSNE&O software system is therefore composed of five separate analysis programs. A typical analysis run requires the execution of several of these system elements. The following is a list of the separate analysis programs and their purpose:

TRACE – Ephemeris Generation and Orbit Estimation

DETECT – Sensor Modeling and Observation Generation

MEAS – Observation Corruption and Editing

ODCOV – Graphical Display and Summary

DARP – Cumulative Statistical Analysis

Summaries of the characteristics of the two major analysis programs and the other analysis elements comprising the SSNE&O software system are presented below.

TRACE – Ephemeris Generation and Orbit Estimation

The TRACE (Ref. 2) computer program, suitably modified, is used to generate reference ephemerides for tracked objects and space-based sensor vehicles and for simulation of the operational orbit estimation process. TRACE capabilities used in the SSNE&O study include the following:

1. Accurate numerical integration

   a. Cowell formulation of equations of motion

   b. Predictor-corrector eighth-order Gauss-Jackson differencing technique

   c. Fourth-order Runge-Kutta method for starting and halving procedures

2. Sophisticated force model capability

   a. Gravitational potential spherical harmonics of up to 350 terms

   b. Segmented or polynomial representation of ballistic coefficient

   c. Large selection of standard atmospheric density models

   d. Discrete orbit adjusts

   e. Solar radiation pressure effects

   f. Gravitational perturbations due to other bodies

3. Analytic partial derivatives via variational equations

4. Orbit estimation techniques

   a. Batch differential correction by weighted least squares

b. Sequential batch differential correction by weighted least squares

c. Batch weighted least squares covariance analysis

DETECT — Sensor Modeling and Observation Generation*

The DETECT (Ref. 3) computer program, extensively modified, is used to generate uncorrupted ("perfect") observations of object vehicles for the orbit estimation process. The DETECT program was originally developed at The Aerospace Corporation and later revised at the Directorate of Aerospace Studies, Kirtland Air Force Base. DETECT was then extensively altered and extended at The Aerospace Corporation for the SSNE&O project. The current capabilities of the DETECT program are summarized as follows:

1. Ephemeris capability

   a. Uses highly accurate ephemerides supplied by TRACE

   b. Can generate two-body ephemerides

2. Ground-based sensor model

   a. Radar sensors

      (1) Pointable elliptical conic visibility volume

      (2) Additional azimuth, elevation, and range rate constraints

      (3) Range constraint a function of object magnitude

   b. Visible light sensors

      (1) Pointable elliptical conic visibility volume

      (2) Additional azimuth, elevation, range, and range rate constraints

*A description of modifications to the DETECT computer program subsequent to the publication of Ref. 3 are available internally to The Aerospace Corporation in ATM-77(2406-01)-10.

(3) Solar/lunar eclipsing and lighting constraints

3. Space-based sensor model

   a. Visible light and LWIR sensor capability

   b. Multiple sensors per sensor vehicle

   c. Flexible visibility volume and scan time specification including inertial stabilization

   d. Complex S/N expressions are functions of object characteristics, zodiacal background, and solar, lunar, and earth radiation

   e. n out of m consecutive hit logic

   f. Automatic change from search to track mode after acquisition logic is satisfied

   g. Ground and/or space readout capability

MEAS – Observation Corruption and Editing*

The MEAS computer program was written specifically to apply noise and bias and to edit the uncorrupted observations supplied by DETECT. Capabilities of the MEAS program are:

1. Applies Gaussian white random noise, with specified standard deviation for each sensor, to observations.

2. Applies Gaussian distributed random biases, with sensor dependent standard deviations, on a pass-by-pass or total flight basis.

3. Edits ground-based visible light sensor observation passes based on sensor site dependent monthly cloud distribution data and a random draw.

*A complete description of the MEAS computer program is available internally at The Aerospace Corporation in ATM-77(2406-02)-2.

4. Edits sensor observation passes based on a random outage model with specified mean and standard deviations for each sensor.

The MEAS program is designed so that any combination of the above capabilities can be executed selectively.

ODCOV – Graphical Display and Summary*

The ODCOV program was written specifically for the SSNE&O software system to display the results of a single Monte Carlo least squares orbit estimation or a covariance analysis execution. Two plots are commonly generated for each system execution. The first plot is a composite. The root sum square (rss) of position differences between the reference and estimated trajectory over the entire orbit determination and predict time intervals are superimposed upon a plot of the observation passes obtained by the sensor network during the orbit determination interval. Figure 4 is an example of this plot. The second standard plot contains the rss of position differences over the predict interval and an envelope curve of the local maxima as a function of predict time. Figure 5 is an example of this type of plot. In addition to graphical output, the ODCOV program generates a summary print of the estimation process and a summary entry in a data file for further processing. In general, all output except this summary print and the standard plots is deleted from a standard system execution.

DARP – Cumulative Statistical Analysis**

The computation of cumulative results from a sequence of Monte Carlo repetitions of the estimation process is accomplished by the DARP program. The input to DARP is the summary file generated by ODCOV. Several types of data representation are possible. Basically, cumulative statistics from a set of Monte Carlo repetitions can be represented in several coordinate systems and geometric units.

Figure 6 is a schematic of the software execution order. A comparison of Figures 1 and 6 shows the correspondence between individual system elements and the basic analysis method.

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*A complete description is available internally at The Aerospace Corporation in ATM-77(2406-01)-9.

**A complete description is available internally at The Aerospace Corporation in ATM-77(2406-02)-1.

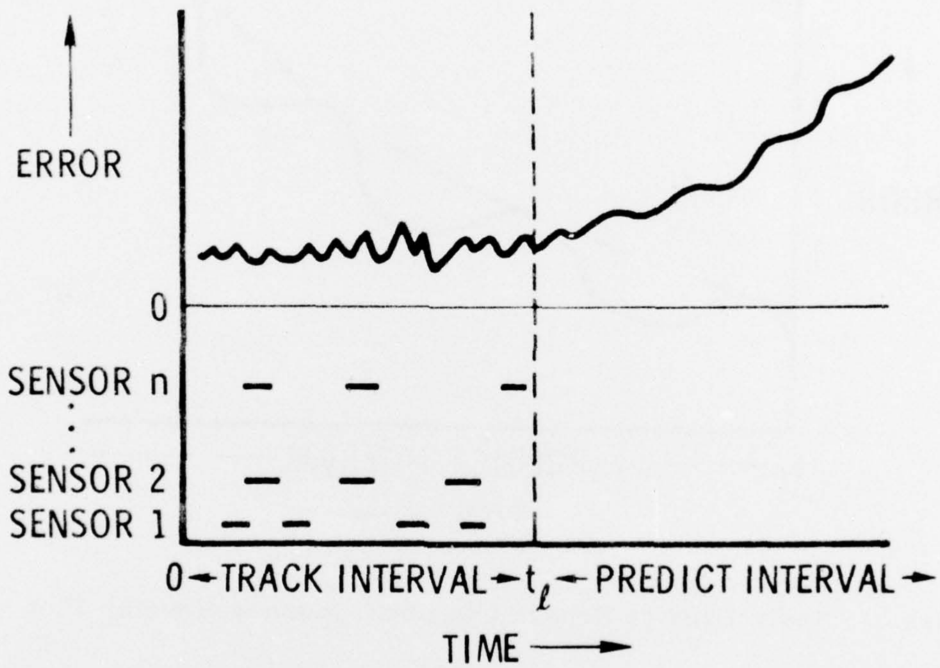

Figure 4. Basic Observation History and Estimation Errors Plot

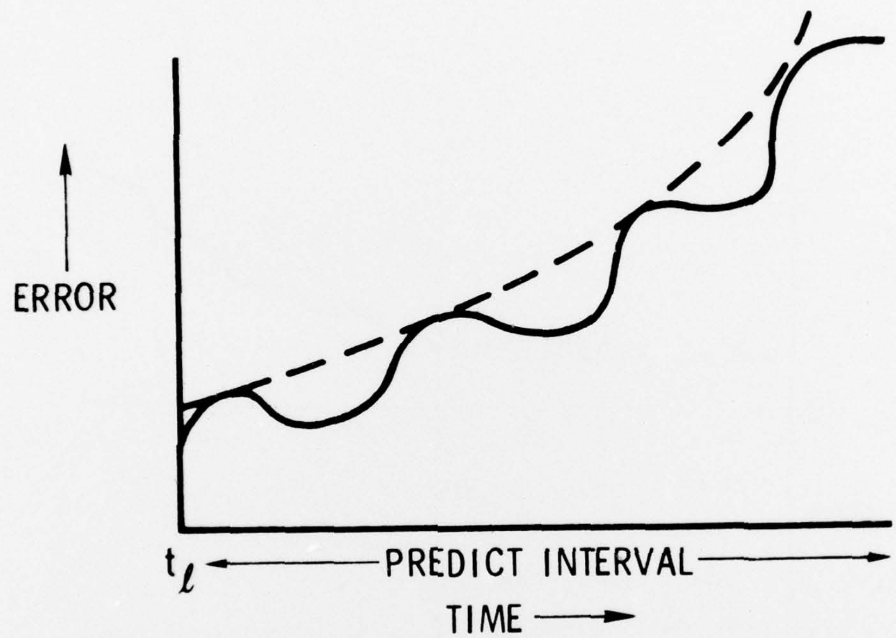

Figure 5. Basic Predict Errors and Local Maxima Envelop Plot

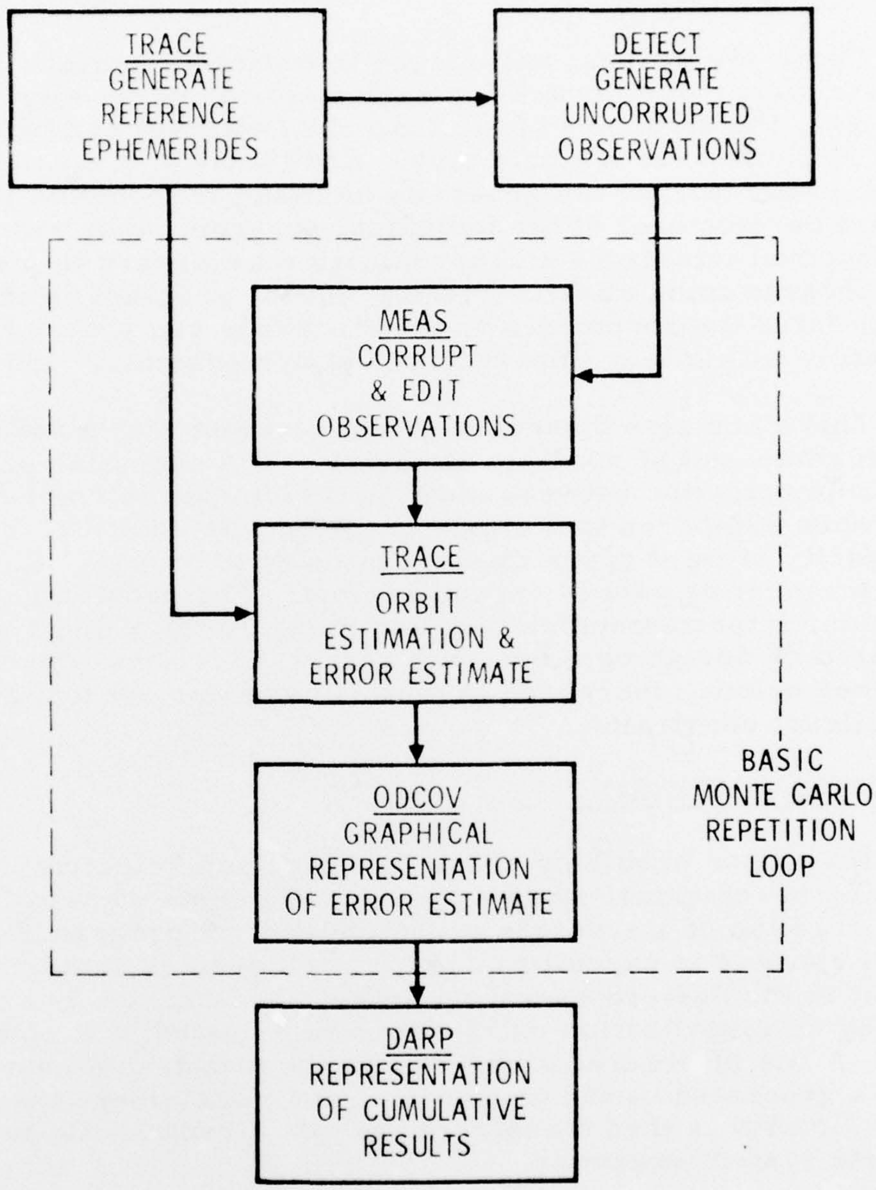

Figure 6. Software Element Configuration

ADVANTAGES AND DISADVANTAGES OF MULTIPLE SYSTEM ELEMENTS

There are several advantages to having essentially separate pieces of software for each major analysis step. Obviously, the structure of the individual element can be more easily optimized for a single task. Additionally, a single programmer/analyst can generally be made responsible for the total development of the individual program, thus reducing the personnel interfaces and coordination necessary in a combined programming effort. Finally, initial program validation and any later improvements or modifications can proceed separately with minor impact on the entire system.

There are also disadvantages associated with a software system composed of multiple elements. The execution of and intercommunication between individual elements is cumbersome when compared to a single program. In addition, a multiplicity of input types can be confusing to a user. Finally, a penalty must be paid in execution time. The problems of execution, intercommunication, and multiplicity of input were alleviated by designing a separate control executive which is described below. Increased execution time was not found to be a significant constraint.

EXECUTION CONTROL

The major problems of the interface and selective execution of individual system analysis elements were solved by the creation of a separate execution control program.* The control element is executed once for each desired analysis element in the desired execution order. This series is preceded by an initialization entry and is terminated by a cleanup entry. A file of ordered directives to the mainframe computer is generated by the sequence of control element executions. Control is then transferred to this directive file to complete system execution.

The initialization entry causes the control program to obtain all necessary mass storage files including binary versions of individual analysis elements and sun/moon ephemeris files. A data entry for an automated accounting system is also generated.

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*A complete description is available internally at The Aerospace Corporation in ATM-77(2406-01)-7.

The control element entry corresponding to each desired analysis program is directed by a set of input flags passed in the argument list of the control element execution command. A set of six flags is input. One flag selects the appropriate analysis element, two determine input mass storage file selection, two determine output file selection, and one regulates printed output. Based on these flags and knowledge of element characteristics, the control program sets up all necessary input/output (I/O) linkage and execution directives for the designated analysis element. In addition, a list of input configuration commands is read and processed. These commands are used to select and/or modify input decks resident on a common data base file. The data base file is basically a translation of the information gathered by the data base acquisition process described above into formats suitable for assimilation by the various software elements. Other information defining the "reference" and "operational" dynamic models along with program control options is also included.

In addition to performing cleanup, the final execution of the control element reads an additional record that may contain nonstandard mainframe directives. Examples would be file manipulations, core dumps, or error procedure control.

Advantages to the control element form of execution are:

1. Essentially all errors in execution control and data file interface are removed.

2. Input to only one software element (the control program) is required.

3. The physical size of input decks is greatly reduced.

4. Selection of input streams from a common data base greatly reduces input error.

5. All types and formats of input can be combined in the data base.

6. Continuity of the data base is easily maintained for reconstruction of previous analysis.

Figure 7 presents the logical flow of the control element.

REMOTE TERMINAL INPUT

The extremely large number of software executions necessary to complete the network evaluation study led to one further operational technique. All run submittals to the mainframe computer are made via a remote terminal. All input decks actually reside on disk files accessible to the remote terminal system. These basic input decks, which contain the required input configuration commands to the control element, can be modified by typed instructions from the terminal console. To submit an analysis run from the terminal, it is only necessary to attach the proper input deck from disk, make at most minor changes by use of terminal editing instructions, and batch the revised input deck to the mainframe. Several advantages accrue from this technique of run submittal:

1. No card input is required, which increases reliability and decreases logistical problems.

2. Run submittal is extremely fast, which reduces manhours significantly.

3. Simultaneous submittal of similar runs creates no logistics problems (as with card decks).

4. Creation and storage on disk of new input decks is fast and simply accomplished.

5. Continuous monitoring of mainframe I/O queues is possible.

6. Direct communication with computer operators is available.

7. Input errors are greatly reduced because of deck standardization.

The large number of separate network analysis cases required could never have been realized within the time specified without use of a remote submittal technique or expansion of the available manpower.

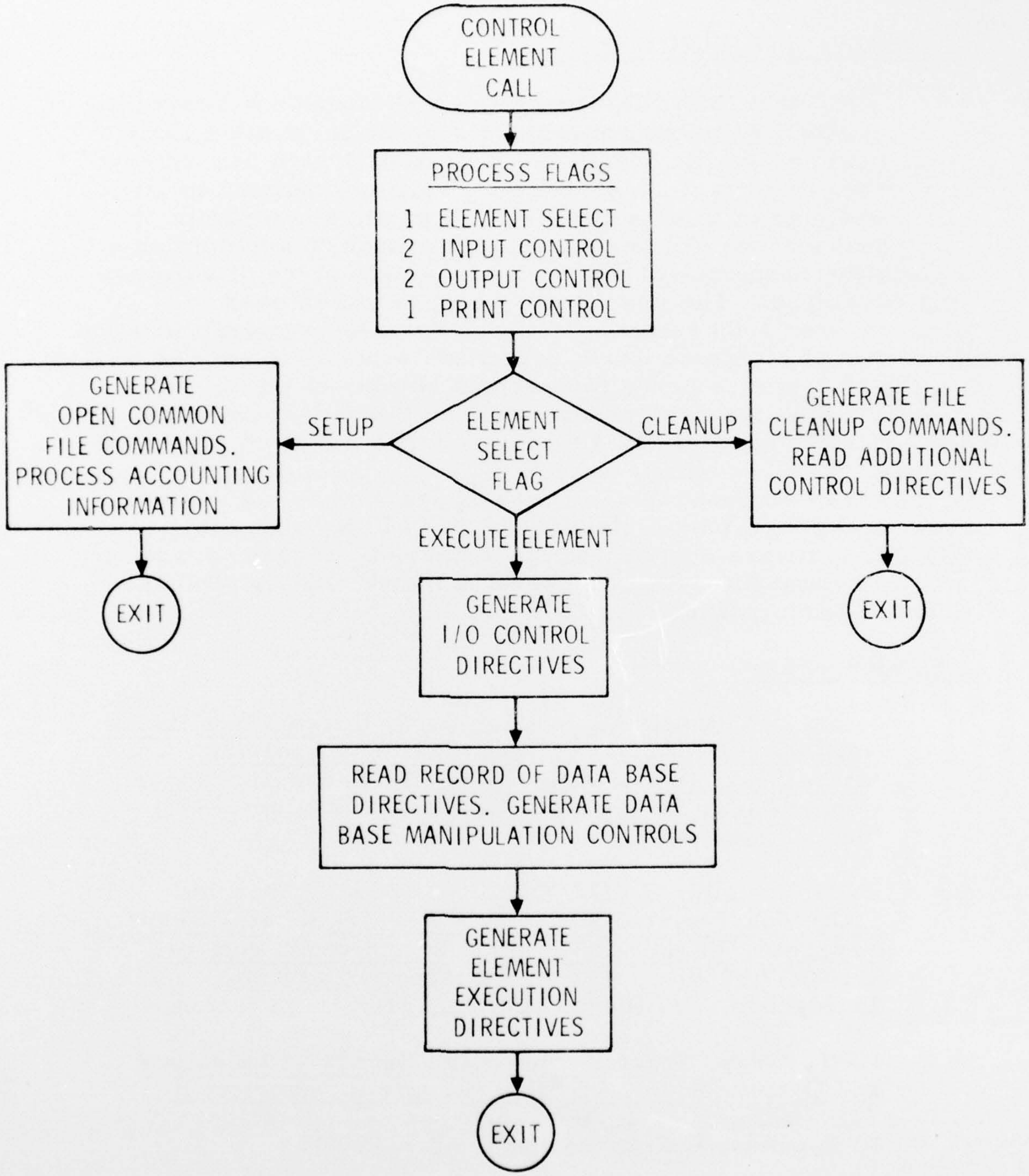

Figure 7. Execution Control Element

SUMMARY AND CONCLUSIONS

The Space Surveillance Network Evaluation & Optimization (SSNE&O) software represents a practical system for a large scale scientific simulation. System design was subject to several important constraints that are not unusual in large scale projects of this nature. In this case, a composite of individual software elements flexible enough to accomplish all simulation requirements instead of a single piece of software was developed. The resulting system has been used to process over 1000 separate network evaluation cases including a number of 30 Monte Carlo repetition sets. The results of a series of separate cases for various objects of interest are used to define the performance of a single sensor network. A total of approximately 15 sensor networks has been evaluated to date. Each candidate sensor network contains up to 30 out of a total of 40 ground- and space-based sensors of various types and geographic distribution. It is likely that the SSNE&O software system, which appears to possess a unique analysis capability, will be used for future studies of sensor network performance.

REFERENCES

1. J. L. LeMay and A. L. Blackford, Space Surveillance Network Evaluation and Optimization: Analysis Methodology (U), TOR-0075(5477)-3, The Aerospace Corporation, El Segundo, California (27 June 1975) (Secret Report).

2. R. H. Prislin, D. C. Walker, and R. J. Mercer, TRACE66 Trajectory Analysis and Orbit Determination Program, Volume I: General Program Objectives, TR-0059(9320)-1, The Aerospace Corporation, El Segundo, California (August 1971).

3. P. T. Gray, Space Surveillance Network Evaluation and Optimization: DETECT Program Description, TOR-0076(6503)-1, The Aerospace Corporation, El Segundo, California (December 1975).